

Architectural Decision Management for Digital Transformation of Products and Services

Alfred Zimmermann¹, Dierk Jugel^{1,2}, Kurt Sandkuhl²,
Rainer Schmidt³, Christian Schweda¹ and Michael Möhring³

¹ Reutlingen University, Faculty of Informatics, Alteburgstraße 150, 72762 Reutlingen, Germany

² University of Rostock, Faculty of Computer Science and Electrical Engineering, Albert-Einstein-Straße 22, 18059 Rostock, Germany

³ Munich University of Applied Sciences, Faculty of Computer Science and Mathematics, Lothstraße 64, 80335 München, Germany

{alfred.zimmermann, dierk.jugel, christian.schweda}@reutlingen-university.de,
{kurt.sandkuhl, dierk.jugel}@uni-rostock.de, rainer.schmidt@hm.edu, michael.moehring@htw-aalen.de

Abstract. The digitization of our society changes the way we live, work, learn, communicate, and collaborate. The Internet of Things, Enterprise Social Networks, Adaptive Case Management, Mobility systems, Analytics for Big Data, and Cloud services environments are emerging to support smart connected products and services and the digital transformation. Biological metaphors of living and adaptable ecosystems provide the logical foundation for self-optimizing and resilient run-time environments for intelligent business services and service-oriented enterprise architectures. Our aim is to support flexibility and agile transformations for both business domains and related information technology. The present research paper investigates mechanisms for decision analytics in the context of multi-perspective explorations of enterprise services and their digital enterprise architectures by extending original architecture reference models with state of art elements for agile architectural engineering for the digitization and collaborative architectural decision support. The paper's context focuses on digital transformations of business and IT and integrates fundamental mappings between adaptable digital enterprise architectures and service-oriented information systems. We are putting a spotlight on the example domain – Internet of Things.

Keywords: Decision support, decision analytics, digital enterprise architecture, collaborative decision environment, and digital transformation.

1 Introduction

Digitization is the collaboration of human beings and autonomous objects beyond their local context using digital technologies. Digitization further increases the importance of information, data and knowledge as fundamental concepts of our everyday activities [1]. By exchanging information human beings and intelligent objects are able to make decisions in a broader context and with higher quality. Social networks, smart portable devices, and intelligent cars represent only a few instances of a pervasive, information-driven vision [2] for the next wave of digital economy and better-aligned information systems. Major trends for the digitization are investigated by [3] itemizing the digitization of products and services, context-sensitive value creation, consumerization of IT, digitization of work, and the digitization of business models.

The Internet of Things, Adaptive Case Management, Decision Support Systems, Mobility Systems, and Services for Big Data in Cloud Ecosystems are emerging to support intelligent user-centered and social community systems. They will shape future trends of business innovation and the next wave of information and communication technology. Biological metaphors of living and adaptable ecosystems provide the logical foundation for self-optimizing and resilient run-time environments for intelligent business services and related distributed information systems with service-oriented enterprise architectures.

The technological and business architectural impact of digitization has multiple aspects, which directly affect adaptable digital enterprise architectures and their supported systems. Smart companies are extending their capabilities and continuously managing their changing Business Operating Model [4] by developing and maintaining Enterprise Architectures as the architectural part of a changing IT Governance [5]. Enterprise Architecture Management [6] and Services Computing is the approach of choice to organize, build, utilize, and distribute capabilities for the digital enterprise architectures [7]. They provide flexibility and agility for business and IT systems and open a new path for stakeholder collaboration, joint analytics, and cooperative decision support. The current paper extends the basic version of [8] by special multi-perspective decisional methods and instruments, added fundamentals about digital architectures, and the application context of digital transformation with the Internet of Things. The development of such applications integrates Web and REST Services, Cloud Computing and Big Data management, among other frameworks and methods for architectural semantic support.

Today's information systems span a broad range of domains including: intelligent mobility systems and services, intelligent energy support systems, smart personal health-care systems and services, intelligent transportation and logistics services, smart environmental systems and services, intelligent systems and software engineering. One of the challenges is the safe integration of mobile devices into managed enterprise architecture of both business and IT. Nowadays it is much easier to work together over large distances, which often allows an uncomplicated outsourcing of business tasks. Businesses need to adapt and have to rethink their business models to develop them innovatively according to employees' current skills and competencies.

Digitization of products and services [1] requires the close alignment of business models and digital technologies for creative digital strategies and solutions, as well as for their digital transformation. Unfortunately, the current state of art and practice of enterprise architecture lacks an integral understanding and support of collaborative decisions in the process of architectural adaptation and enterprise transformation. Our main motivation and the current presented work is to extend previous approaches of quiet static enterprise architecture to fit flexible and adaptive digitization of new products and services and, by introducing suitable mechanisms for collaborative architectural engineering and decision support with adaptive case management for agile changing business models, information systems and their digital enterprise architecture. We report about our work in progress research to provide a unified collaborative decision framework for adaptable digital enterprise architecture models from relevant information resources of digital products and services and their digital transformation.

The paper investigates the following questions:

RQ1: What is the architectural context from the domain of digital transformation for products and services?

RQ2: How digital enterprise architecture should be tailored to fit for the digital transformation using mechanisms of adaptation and current architectures for the Internet of Things?

RQ3: How can collaborative mechanisms for decision analytics be specifically designed by introducing decision-making viewpoints and environments for investigating and flexibly changing digital enterprise architectures?

The following Section 2 describes the context of digital transformation for the next digitized products and services. Section 3 provides the digitization context with the Internet of Things. In

Section 4 we describe our research platform of digitization architecture, which was extended by concepts from adaptive case management, architectural adaptation mechanisms and a specific model integration method. Section 5 presents our collaborative architectural engineering and transformation environment and links it with specific multi-perspective decisional viewpoints. In Section 6 we focus on collaborative decision analytics techniques and present a decisional metamodel for digital enterprise architectures. Section 7 shows an illustration of a collaborative decision scenario by a concrete example from a virtual insurance company. In Section 8 we point to some relevant and inspiring related work results. Finally, we summarize in Section 9 our research findings, our ongoing work in academic and practical environments and our future research plans.

2 Digital Transformation

Digitized products and digitized services are both software-intensive and, therefore, malleable and usually service-oriented and easily adaptable. They are able to increase their capabilities accessing cloud-services and change their behavior. Digitized products support the co-creation of value together with the customer and other stakeholders [1]. Digitized products and services offer disruptive opportunities for new business solutions having new smart connected functionalities. At first, the high level of interest in digitalization surprises, because the digital representation of information and performing digital calculation operations have been established for decades. The term digitization has its origin in [9] and is used for the digital representation of information, and processing for years [10], [11].

There are definitions that consider digitization primarily a technical term [12]. Technologies often associated with digitization [13] are: cloud computing [14], big data [15] and [16] advanced analytics, social software, and the Internet of Things [17]. The set of technologies increases. New technologies such as deep learning [18] are emerging that allow computing to be applied to activities that were considered as exclusive to human beings.

Therefore, the question arises: what causes the present emphasis on digitization and what is different about digitization? Our thesis is that digitization today embraces effects from both a product and a value-creation perspective. Digitization can be described from both a product and a value-creation perspective: digitized products and the digitized value chains. Digitized products offer new capabilities of interacting with their environment and the customer. They are also capable of collecting data.

Classic industrial products are static [19]. You can either not change the products or do so only to a limited extent. Digitization creates products containing software that can be upgraded via network connections. In addition, products over network connections can use external services. Software and especially services are also easier to update. New software functions can be added and additional services can be integrated. Therefore, the functionality of products is no longer static, but can be adapted to changing requirements and hidden customer needs [20]. In particular, it is possible to create digitized products and services step-by-step or provide temporarily unlockable functionalities. So customers whose requirements have risen can add functions without hardware modification.

Digitalization [1] allows products to capture their own state and submit this information into linked contexts. The provider can remotely determine whether the product is still functional and encourage, where appropriate, maintenance and repairs. This is the basis on which, instead of the physical product, the use of the product as a service changes the traditional offer. These services will be measured on their effectiveness and their practical usage. This will lay the foundation for usage-based billing models. In addition to the usage information the condition of the product by the manufacturer can also be queried.

In this context, concepts of preventive maintenance [21] can be developed. These have the objective of avoiding unscheduled stoppages whenever possible. Evaluation of status

information and analysis of the history of use of the product can predict, when a malfunction of the product is likely. Maintenance or replacement of the product is performed before the respective date. In this context, the collected data can also be used to provide information for a repair on the spot, so that a high first time solution rate can be achieved. At the same time, in this way the storage of spare parts can be improved.

3 Digitization with the Internet of Things

The Internet of Things [22] enables the creation of products that are constantly communicating with manufacturers. In this way, the manufacturer can win genuine information about the use of the product. The collection of information on the use of products is no longer dependent on the cooperation with the customer. In addition, it is possible to collect important information for up - and cross - selling in this way. By linking devices on networks, benefits are generated from two areas. Both the functionality increases and there are positive effects arising from the overarching data use. Furthermore, the production of more customer-oriented products [23] is possible.

The Internet of Things maps and integrates real world objects into the virtual world, and extends the interaction with mobility systems, collaboration support systems, and systems and services for big data and cloud environments. Sensors, actuators, devices as well as humans and software agents interact and communicate data to implement specific tasks or more sophisticated business or technical processes. Therefore, smart products as well as their production are supported by the Internet of Things and can help enterprises to create more customer-oriented products. Furthermore, the Internet of Things is an important influence factor of the potential use of Industry 4.0 [23].

In the context of current fast changing markets [24] the Internet of Things (IoT) fundamentally revolutionizes today's digital strategies with disruptive business operating models [11] and holistic governance models for business and IT [4], [5]. Reasons for strategic changes by the Internet of Things [24] are: (i) information of everything – enables information about what customers really demand, (ii) shift from the thing to the composition – the power of the IoT results from the unique composition of things in an always-on always-connected environment, (iii) convergence – integrates people, things, places, and information, and (iv) next-level business – the Internet of Things is changing existing business capabilities by providing a way to interact, measure, operate, and analyze business. With the huge diversity of Internet of Things technologies and products, organizations have to leverage and extend previous enterprise architecture efforts to enable business value by integrating the Internet of Things into their classic business and computational environments.

The Internet of Things [17], [22] supports many connected physical devices over the Internet as a global communication platform. The Internet of Things is the result of a convergence of visions [25] like, a Things-oriented vision, an Internet-oriented vision, and a Semantic-oriented vision. A cloud centric vision for architectural thinking of a ubiquitous sensing environment is provided by [24]. The typical configuration of the Internet of Things includes, besides many communicating devices, a cloud-based server architecture which is required to interact and perform remote data management and calculations.

Network effects [26] grow exponentially, because they are based on the number of participants and the number of possible connections. The possibility of connecting devices to the network increases the possible uses of the individual device, because of increasing the number of potential partners. This benefit increases disproportionately higher as the number of devices increases. This is because the number of possible connections grows faster than does such number of devices [27].

This increase of commercial value also happens through services provided by a lot of partners with complementary skills [19]. Software platforms that support the collection, analysis and exchange of data are rapidly growing. Winners in this environment will be companies that enable

network effects to create value for customers. Network effects become apparent not only in functionality, but also in the scope of the data. These effects are called network intelligence [9]. By bringing together data from different network nodes, trends can be detected much earlier and more accurately.

By linking data from different sources [28], it is possible to establish correlations that would not have been possible with the data from a single device. This effect increases with the number of devices. By integrating external data sources, the extraction of relevant information can be improved also. Particularly the ability of big data and advanced analytics helps to process semi-structured and unstructured data.

It is a characteristic of an information system that the involvement of one individual product accelerates the learning and knowledge processes across all products [16]. In this way, a number of other beneficial effects can be achieved such as network optimization, maintenance optimization, improved restore capabilities, and additional evidence against the consideration of individual systems.

The idea that the producer of goods creates value and the value is determined at the moment of exchange of goods is well known. It was tried to transfer this idea on services. However, this led to a service definition, which considers services as a negation of physical goods [29]. Services are not material, but already the missing homogeneity can be challenged for industrial services. Services are also not divisible, i.e. they must be provided as a whole. Services are also not durable; they are not stored, and are provided only at the moment of need.

The basis for the implementation of the co-creation [30] approach of service-dominant logic is the continuous connection of the products to the manufacturer. The manufacturer can gain genuine information about the use of the product. Important information for the development of new products can be obtained in this way. The consumer converts dynamically to be co-producer [31]. Platforms are complementary products, which are defined by the digitization architecture (Section 4) and cooperate via standardized interfaces [32]. Since the development of new functionalities by different partners is distributed, [33] platforms significantly speed-up the development time of new solutions.

4 Digitization Architecture

Our investigation idea for Digital Enterprise Architecture is about an extended analytics approach for systematic composition and integration of architectural metamodels, ontologies, views and viewpoints within adaptable service-oriented enterprise architecture frameworks. The guiding frame and starting point for our work is ESARC - Enterprise Services Architecture Reference Cube [6], [41]. We are extending our digital enterprise framework to an adaptable digitization architecture framework by integrating new architectures for the Internet of Things.

4.1 Digital Enterprise Architecture

ESARC – Enterprise Services Architecture Reference Cube (see Figure 1) comprises an integral service-oriented enterprise architecture categorization framework, which sets a classification scheme for main enterprise architecture methods [34], [35], [36], [37] and standards [38], [39], as a guiding instrument for decisions considering interrelated architectural engineering viewpoints. ESARC completes existing architectural standards and frameworks in the context of EAM – Enterprise Architecture Management [38], [39], [36] and extends these architecture standards for services and cloud computing in a more specific way. ESARC is an original architecture reference model with eight integral architectural domains. ESARC abstracts from a concrete business scenario or from technologies, but is applicable for concrete architectural instantiations.

Metamodels and their architectural data are the core part of the Enterprise Architecture. Enterprise architecture metamodels [39], [42] should support decision analytics [37] and the strategic [43] and IT/Business [34] alignment. Three quality perspectives are important for an adequate IT/Business alignment and are differentiated as: (i) IT system qualities: performance, interoperability, availability, usability, accuracy, maintainability, and suitability; (ii) business qualities: flexibility, efficiency, effectiveness, integration and coordination, decision support, control and follow up, and organizational culture; and finally (iii) governance qualities: plan and organize, acquire and implement, deliver and support, monitor and evaluate.

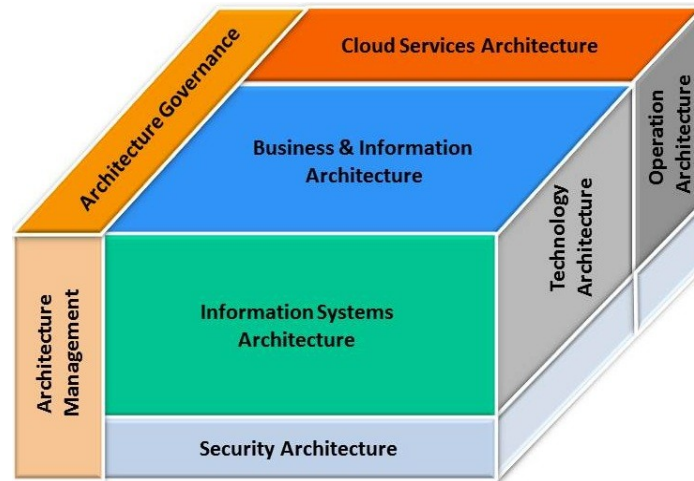


Figure 1. Enterprise Services Architecture Reference Cube [6], [41], [7]

Architecture Governance, as in [5] sets the governance frame for well aligned management practices within the enterprise by specifying management activities: plan, define, enable, measure, and control. The second aim of governance is to set rules for architectural compliance respecting internal and external standards. Architecture Governance has to set rules for the empowerment of people, defining the structures and procedures of an Architecture Governance Board, and setting rules for communication.

4.2 Architecting the Internet of Things

The main question of current and further research is, how the Internet of Things architecture fits in a context of a services-based enterprise-computing environment? Using the classification possibilities and architectural domains of ESARC, we are in the process of extending metamodels for EAM and the Internet of Things [7], and aligning them for supporting Digital Transformation [19], [40]. For this purpose, identification of potentially relevant developments in EAM and in service-oriented architectures was required. The most relevant ones are presented in the following.

A service-oriented integration approach for the Internet of Things is elaborated in [25]. The core idea for millions of cooperating devices is how they can be flexibly connected to form useful advanced collaborations within the business processes of an enterprise. The research in [25] proposes the SOCRADES architecture for an effective integration of Internet of Things in enterprise services. The architecture from [25] abstracts the heterogeneity of embedded systems, their hardware devices, software, data formats, and communication protocols. A layered architecture structures the following bottom-up functionalities and prepares these layers for integration within an Internet of Things focused enterprise architecture: Devices Layer, Platform Abstraction Layer, Security Layer, Device Management Layer with Monitoring and Inventory Services, and Service Lifecycle Management, Service Management Layer, and the Application Interface Layer.

Today, the Internet of Things includes a multitude of technologies and specific application scenarios of ubiquitous computing [17], like wireless and Bluetooth sensors, Internet-connected wearable systems, low power embedded systems, RFID tracking, smartphones, which are connected with real world interaction devices, smart homes and cars, and other SmartLife scenarios. To integrate all aspects and requirements of the Internet of Things is difficult, because no single architecture can today support the dynamics of adding and extracting these capabilities.

A first Reference Architecture (RA) for the Internet of Things is proposed by [44] and can be mapped to a set of open source products. This Reference Architecture covers aspects like: cloud server-side architecture, monitoring and management of Internet of Things devices and services, a specific lightweight RESTful communication system, and agent and code on often small low power devices, having probably only intermittent connections.

A layered Reference Architecture for the Internet of Things is proposed in [44] and (Figure 2). Layers can be instantiated by suitable technologies for the Internet of Things. A current holistic approach for the development for the Internet of Things environments is adapted from [45]. This research has a close link to our work about leveraging the integration of the Internet of Things into a framework of digital enterprise architectures. The main contribution from [45] considers a role-specific development methodology, and a development framework for the Internet of Things. The development framework contains a set of modeling languages for a vocabulary language to describe domain-specific features of an IoT application, an architecture language for describing application-specific functionality, and a deployment language for deployment features.

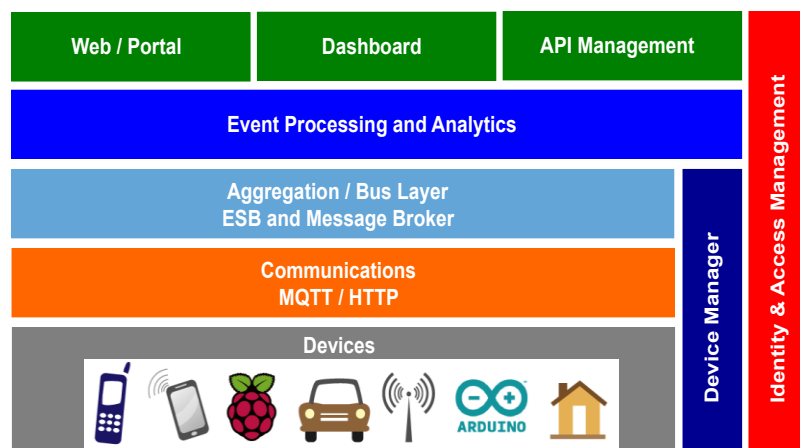


Figure 2. Internet of Things Reference Architecture [44]

Associated with this language set are suitable automation techniques for code generation, and linking to reduce the effort for developing and operating device-specific code. The metamodel for Internet of Things applications from [45] and [46] defines elements of an Internet of Things architectural reference model like, IoT resources of type: sensor, actuator, storage, and user interface. Internet of Thing resources and their associated physical devices are differentiated in the context of locations and regions. A device provides the capability to interact with users or with other devices. The base functionality of Internet of Things resources is provided by software components, which are handled in a service-oriented way by using computational services.

The Internet of Things architecture has to support a set of generic as well as some specific requirements [43], and [44]. Generic requirements result from the inherent connection of a large number of devices via the Internet, often having to cross firewalls and other obstacles. Having to consider so many devices, and a dynamic growing number of them, we need an architecture for scalability. Because these devices should be active in a 24x7 timeframe we need a high-availability approach [46], with deployment and auto-switching across cooperating datacenters in

case of disasters and high scalable processing demands. Additionally an Internet of Things architecture has to support automatic managed updates and remotely managed devices. Often connected devices collect and analyze personal or security relevant data. Therefore, it is mandatory to support identity management, access control and security management on different levels: from the connected devices through the holistic controlled environment.

Specific architectural requirements [44] and [17] result from key categories, such as connectivity and communications, device management, data collection and analysis, computational scalability, and security. Connectivity and communications groups existing protocols like HTTP, could be an issue on small devices, due to their limited memory sizes and because of power requirements. A simple, small and binary protocol can be combined with HTTP-APIs, and has the ability to cross firewalls. Typical devices of the Internet of Things are currently not managed or not well managed by device management functions of the current Enterprise Architecture Management.

Desirable requirements of device management [44] include the ability to locate or disconnect a stolen device, update the software on a device, update security credentials or wiping security data from a stolen device. Internet of Things systems can collect data streams from many devices, store data, analyze data, and act. These actions may happen in near real time, which leads to real-time data analytics approaches. Server infrastructures and platforms should be highly scalable to support elastic scaling up to millions of connected devices, whilst alternatively supporting smaller deployments as well. Security is a challenging aspect of this highly-distributed typical small environment of Internet of Things. Sensors are able to collect personalized data and can bring these data to the Internet.

5 Architectural Engineering and Decision Making

A Decision Support System (DSS) is a system “to help improve the effectiveness of managerial decision making in semi-structured tasks” [47, p. 255], and according to [48]. In particular, knowledge intensive management activities, like Enterprise Architecture Management (EAM), can benefit from a DSS to improve architectural decision-making.

5.1 Enterprise Architecture Cockpit

We are exploring in our current research, how an enterprise architecture cockpit [49], and [50], [51], [52] can be leveraged and extended to a DSS for EAM. A cockpit presents a facility or device via which multiple viewpoints on the system under consideration can be consulted simultaneously. Each stakeholder who takes place in a cockpit meeting can utilize a viewpoint that displays the relevant information. Thereby, the stakeholders can leverage views that fit the particular role like Application Architect, Business Process Owner or Infrastructure Architect [53]. Viewpoints which are applied simultaneously are linked to each other in such a manner that the impact of a change performed in one view can be visualized in other views as well. Figure 3 gives the idea of an example of an architectural cockpit with multi-perspective interrelated viewpoints.

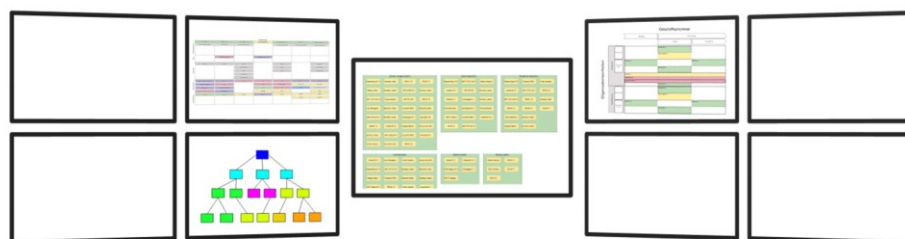


Figure 3. Example: Enterprise Architecture Cockpit [49], [50]

Jugel et al. [51] present a collaborative approach for decision-making for EA management. They identify decision making in such a complex environment as a knowledge-intensive process that strongly depends on the participating stakeholders. Therefore, the collaborative approach presented is built in a way that is based on the methods and techniques of adaptive case management (ACM), as defined in [54].

5.2 Decision Making Scenario

The *Issue* is the starting point of a collaborative decision-making case. This issue describes the problem space of the decision-making activity, which aligns with the perspective of Mayring [59]. We further assume that goals and success criteria, as required by Johnson et al. [60], have already been defined as part of strategic management activities. The issue is the reason why the EA has to be analyzed and decided upon. Based on this issue, involved stakeholders choose viewpoints from which they need to analyze the issue.

The *decision-making step* is the central activity of the decision-making case, as presented in Figure 4. This step can involve different optional activities in which different kinds of quantitative and qualitative analysis techniques [61] are applied to gain additional insights:

- *Expert-based analysis* techniques are dependent on expert knowledge and tacit information possessed by the involved stakeholders. Jugel et al. [49] identify these techniques with interactive functions like “graphical highlighting and filtering”.
- *Rule-based analysis* techniques correspond to algorithms that are used to identify patterns in the EA. Hanschke provides so-called analysis patterns in [62], which are examples of rule-based analysis techniques.
- *Indicator-based analysis* techniques are formal methods that compute indicators from properties of the EA. Matthes et al. [63] present quantitative, metrics-driven EA analysis by quantitatively assessing architectural properties and, therefore, use an indicator-based analysis technique.

Stakeholders apply different ones of these techniques in the decision-making step and interpret the results of the techniques for additional insights [59]. While performing a decision-making step, stakeholders can choose analysis techniques, which are part of a catalog. The catalog is independent of a particular case. After choosing an analysis technique, it is performed. In the case of rule-based and indicator-based analysis techniques, the techniques can be performed automatically using algorithms and aggregations. In the case of an expert-based analysis technique, stakeholders must manually analyze the EA by using and interacting with the cockpit’s views.

The *decision-making step* is based on case data consisting of an EA model and additional insights elicited in previous steps. Consequently, the insights gained during each step contribute to the *case file* (CaseFile) of the decision-making case. Derived values, like the values of KPIs are thereby not considered additional information, but only a different way of representing and aggregating existing information. If stakeholders based on the values of a KPI decide on affected architecture elements, these decisions and considerations represent new information, which is added to the case file. In particular, the stakeholders’ interpretation can yield the following additional elements for the case file (CaseFileItem):

- *An evaluation represents the stakeholder’s opinion on the analysis results,*
- *A new issue refines the previously analyzed one based on the analysis,*
- *A decision reflects a design alternative that is useful to resolve the issue.*

During the decision-making, alternative designs can be identified [60]. In the final step of the decision-making process, not all previously evaluated designs will prevail. At the end of every *decision-making step*, the stakeholders have to decide whether additional information is required

or not – represented by UserEventListeners in the CMMN diagram in Figure 4. The case file of the decision-making case has to be structured appropriately to accommodate the decision-making process.

5.3 Adaptive Case Management

Adaptive Case Management (ACM) [54], [55] and [65] offers a lightweight model to support knowledge-intensive processes, which are driven by user decision-making. Knowledge processes of usually high-skilled stakeholders, like enterprise architects, require process adaptations at run-time. ACM is not dictating a predefined course of action [64] and provides the necessary information and knowledge support to be able to solve a case.

A case [54] is typically a collection of all relevant information into one place, which is handled by one or more knowledge workers during the solving of this case. The case is the jointly used focal point for assessing the situation, initiating activities and processes, implementing the work, and reflecting results based on a history record about what was really done. A case brings together all the necessary resources and also tracks everything that has happened into a history record, which can be mined to synthesize best practices, patterns of success, and instruments that have been used and extended instruments.

As opposed to routine work, which can be supported by business process management, because of its repeatable kind, knowledge work is typically unpredictable. Knowledge workers [56], [57] are acting under uncertainty. An unpredictable process [55] does not repeat in routine patterns and emerges as the work is done. The practice of preparing for many possible courses is called agility. Differentiating between seven domains of predictability [55] case management can be focused on just two main types:

1. *Product Case Management: Supports design-time knowledge processes with a well-known set of actions, having much variation between individual cases. It is not possible to set out a single fixed process. Knowledge workers are actively involved in deciding the course of events for a case.*
2. *Adaptive Case Management: Knowledge workers are involved not only in the case, and picking predefined actions, but they are constantly adapting the process and striving for innovative approaches, and may want to share and discuss process plans.*

5.4 Decision Modeling

The Case Management Modeling Notation (CMMN) [58] is a notation for ACM that describes mandatory and optional tasks (DiscretionaryItem), and thereby supports flexible processes. In line with Jugel et al. [51], we utilize CMMN to describe a collaborative decision-making case for EAM, cf. Figure 4.

The Object Management Group (OMG) has published the Case Management Model and Notation (CMMN) [58] as a first step to support modeling for case management scenarios [64]. In [65] a case study was implemented of a TOGAF-style process [38] for EAM with CMMN. The upcoming standard Decision Model and Notation (DMN) of OMG [66] discerns three usage models: for modeling human decision-making, for modeling requirements for automated decision-making, and for implementing automated decision-making.

DMN bridges the gap between business decision designs and their implementation by providing a common notation for decision models. The purpose of DMN is to facilitate a decision model framework, which is easily usable for decision diagrams and as a base for optionally automating decisions. Decision-making support is addressed from basically two perspectives: normal BPMN business Process Models can be expanded by defining specific decision tasks, or decision logic can be used to support individual decisions, e.g., business rules, decision tables, or executable analytic models. DMN can additionally provide a third perspective

to bridge between business process models and decision logic by introducing the Decision Requirements Diagram.

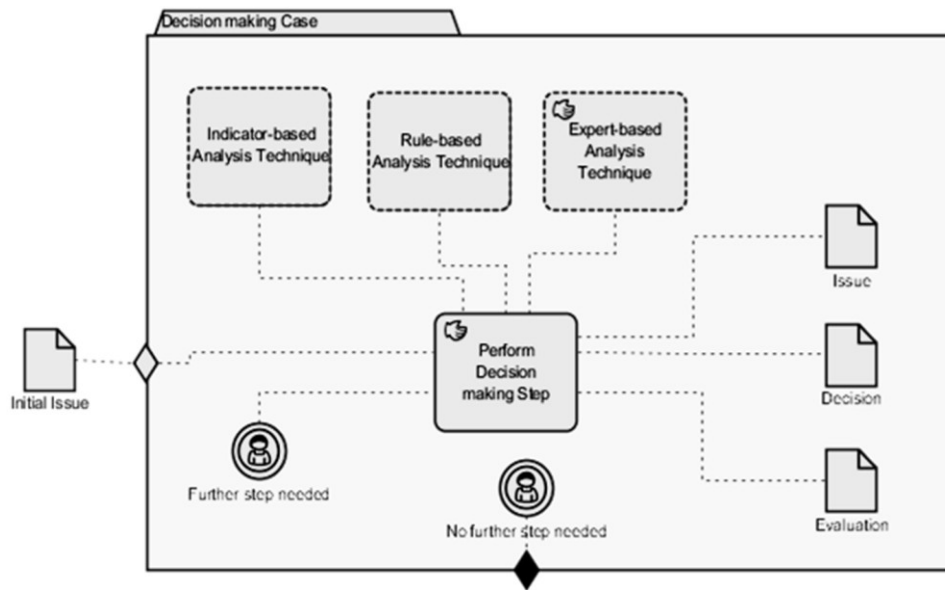


Figure 4. CMMN Model of Collaborative Decision Making Case [51]

Complementary to the DMN notation, which is used to model decisional relationships and concepts like Decision, Input Data, Business Logic, Application, Application Risk, etc.; DMN introduces an expression language to represent decision tables, decision rules, and function invocations. Today we are exploring the suitable usage and close link of DNM for decisional support logic within our architectural engineering and analytics research.

6 Decision Analytics Metamodel

We are extending the decisional metamodel by closely related decisional concepts based on the work of Jugel et al. [50], [51] to support the decision-making case presented in the previous section. The metamodel focuses on the documentation of decisions and rationalizing information as a combination and extension of related approaches that each cover local aspects of our extended decision-making model:

- *Plataniotis et al. [67] describe an approach called “EA Anamnesis” focusing on ex-post modeling EA decisions and decision-making strategies. However, they do not describe decision processes. Furthermore, they do not describe rationales.*
- *ISO Standard 42010 [68] describes how the architecture of a system can be documented using architecture descriptions. The standard uses views, which are governed by viewpoints to address stakeholders’ concerns and their information demands.*
- *Jugel et al. [49] introduce an annotation mechanism to add additional knowledge to an architecture description, which is represented by an extended EA model. In addition, they refine in [50] the viewpoint concept of [67] by dividing it into Atomic Viewpoint and Viewpoint Composition to model coherent viewpoints that can be applied simultaneously in a cockpit to support stakeholders in decision-making.*
- *Buckl et al. [61] provide a classification of analysis techniques that can be used to get insights into an EA. Stakeholders in decision-making use analysis techniques.*

The Case Management Modeling Notation (CMMN) [58] is a notation for ACM to describe flexible processes including optional tasks. The notation provides us base concepts to model suitable decision cases. Figure 5 illustrates the extended decisional metamodel.

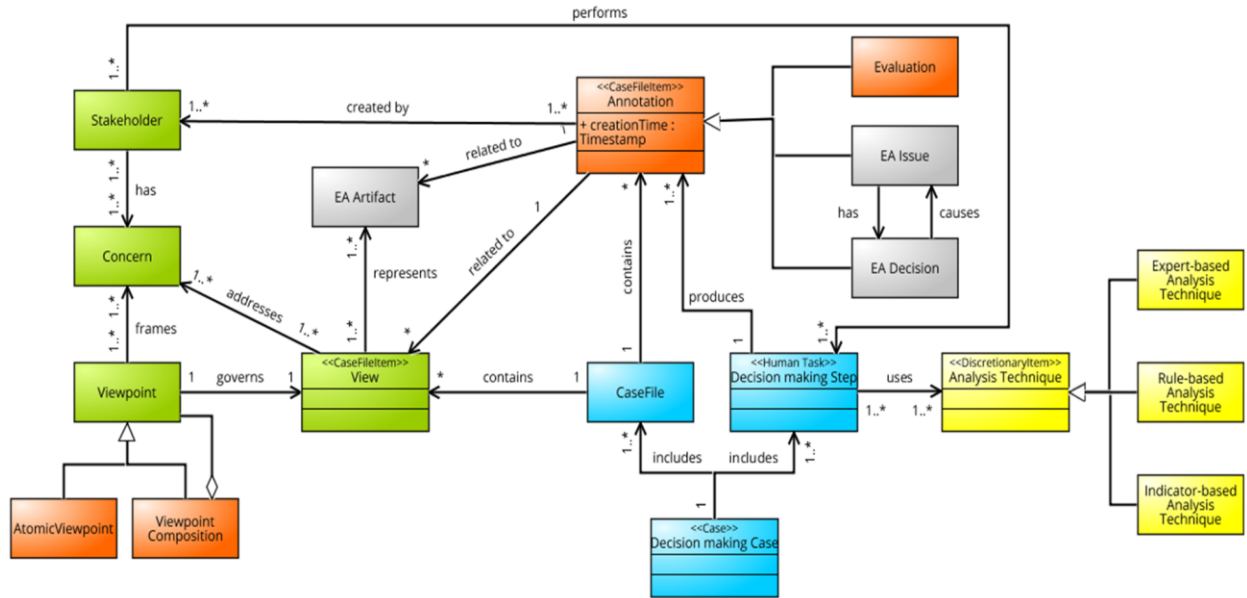


Figure 5. Collaborative EA Decision Making Metamodel

The background colors of the concepts indicate their origin. Green colored concepts have their origin in ISO Standard 42010 [68], gray colored concepts in “EA Anamnesis” [67], blue colored concepts in CMMN [58], yellow colored concepts in [61] and red colored concepts in [49] and [51]. The decisional metamodel focuses on the stakeholders using viewpoints to perform a Decision making Step that is in line with CMMN [58]; a HumanTask. During this step, stakeholders can choose Analysis Techniques that are in line with CMMN [58] Discretionary Items. Additional information during a step is created, and persisted with, as Annotations to the decisional views. Annotations as well as Views are in line with CMMN [58] CaseFileItems, because both represent relevant information within a case and are, therefore, part of a CaseFile. The annotation concept aligns with the one presented by Jugel et al. in [49] and reflects different EA issues (also the initial one of the decision case), Evaluations of the analysis results, and EA decisions. As the annotations can be based on the results of an analysis technique, also the applied techniques are part of the metamodel and are persisted with in the CaseFile. The latter notion corresponds to the terminology of CMMN.

For the utilized viewpoints, we distinguish between Atomic Viewpoints and Viewpoint Compositions [51]. Whereas an Atomic Viewpoint is a single Viewpoint in line with ISO Standard 42010 [68], a Viewpoint Composition forms a composite structure and consists of coherent Atomic Viewpoints or other Viewpoint Compositions needed by Stakeholders to satisfy their information demands elicited by their Concerns. Viewpoint Compositions are assembled to address a specific decision-making case from multiple perspectives. A cockpit, as presented in the previous chapter, is a viewpoint composition.

In addition, Annotations are the triggers for the next Decision Making Step. One or more Stakeholders are responsible for each step and perform them. Within a Decision Making Step stakeholders can choose between different Analysis Techniques to get additional information needed to satisfy their information demands. Analysis Techniques are based on Annotations as well on the EA model. Annotations describe additional information related to EA Artifacts. EA Issues and EA Decisions, as already present in the model of Plataniotis et al. [67], represent additional knowledge and are, therefore, specializations of Annotation. As described in [67], EA Decisions can be decomposed, translated and substituted into other EA Decisions. Modeling alternatives is also possible. According to our decision-making case, we added Evaluation as a third sub-concept of Annotation.

7 Decision Modeling Case

In this section we adapt, as an example, the case of Plataniotis et al. [67] to illustrate our collaborative decision modeling approach by applying concepts from the decision analytics metamodel (see Section 5). The case, used as an example, is based on ArchiSurance, a virtual insurance company introduced to demonstrate the capabilities of ArchiMate [39].

In our example we assume that ArchiSurance hires an external consultant - John. He is a business consultant with experience in implementation and adaptation of business models. His mandate is to change ArchiSurance's sales model from direct sales towards a sales model with intermediaries. As changing the business model has several impacts on the underlying applications and infrastructure he directly involves Mike and Jack. While Mike has the application responsibility, Jack is an infrastructure and security expert. Each of them has particular concerns and both need particular viewpoints to satisfy their information demands.

7.1 Architectural Decision Assessment

To analyze the current state of the EA and to work out implementation alternatives, John, Mike and Jack, i.e., the stakeholders involved, meet at an Architecture Cockpit, for example as described by Jugel et al [49]. To satisfy their information demands, they use the following viewpoints from ArchiMate [39]: Business Process Viewpoint, Application Usage Viewpoint and Infrastructure Usage Viewpoint.

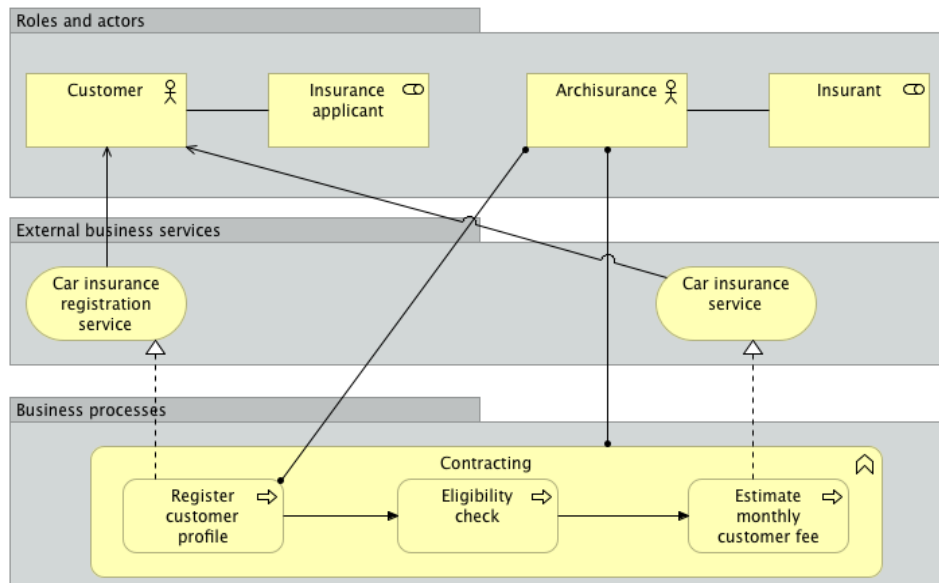


Figure 6. Business Process Viewpoint

Figure 6 shows an example for the Business Process Viewpoint while Figure 7 presents the Application Usage Viewpoint. The Business Process Viewpoint shows the overall context about ArchiSurance's sales model. By using this information, John wants to adapt the sales model. The Application Usage Viewpoint describes the applications, their application services and the business processes they support. The Infrastructure Usage Viewpoint required by Jack describes the dependencies between the infrastructure and the hosted applications.

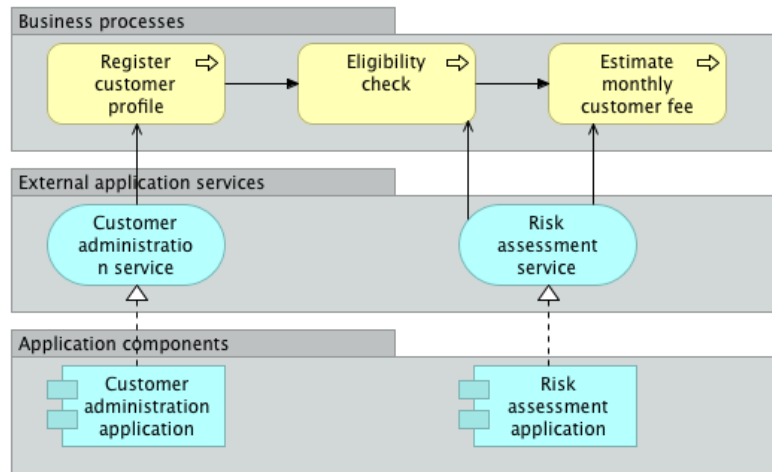


Figure 7. Application Usage Viewpoint

The starting point for EA decision-making according to Plataniotis et al. [67] is an *EA Issue*. The issue in our example is the demand to change the sales model to enable intermediaries. Thus, John creates an *EA Issue* named “Intermediary sales model” and relates it to the Business Process Viewpoint. Thus, John has identified the business function “Contracting” as the main affected object. He creates some *Detailed Information* named “Main affected business function”, relates it to the business function and styles it with a red fill color to visually highlight it. As nobody knows whose responsibility this business function is, John creates a *Task* named “Clarify responsibilities” to clarify it until the next meeting, because this is an additional stakeholder that has to be involved.

Afterwards John suggests his idea by creating the *EA Decision* “Changing the sales model”. John has the opinion that the business process “Register customer profile” has to be separated from the business function “Contracting”. He recommends creating a new business function named “Create customized insurance package”. The results of his suggestion can be modeled according to [68] by relating the impacted *EA Artifacts* to one of the defined relationship types, i.e. a new *EA Artifact* named “Create customized insurance package” of the type “business function” is needed and has to be related to the *EA Decision* by an “introduces” relationship. Furthermore, the business process “Register customer profile” has to be retired, to realize the new demand, by being superseded by a new business interaction named “Customer profile registration”.

7.2 Decision Process Results

Decisions usually trigger systematic changes in architectural models. The results of these changes are adapted viewpoints. Figure 8 shows the result of John’s suggestions for adapting the sales model. In the figure elements with a green fill color are *EA Artifacts* that have to be introduced whereas elements that have to be retired have a blue fill color. Furthermore, the *EA Artifact* with the red fill color represents the *Information* “Main affected business function” described above.

Mike recognizes that changing the business process “Register customer profile” is the only change in the business model that may have impacts on underlying applications and infrastructure. He documents this finding by creating a *Detailed Information* named “May have impacts on applications and infrastructure” and relates it to the business process “Register customer profile”.

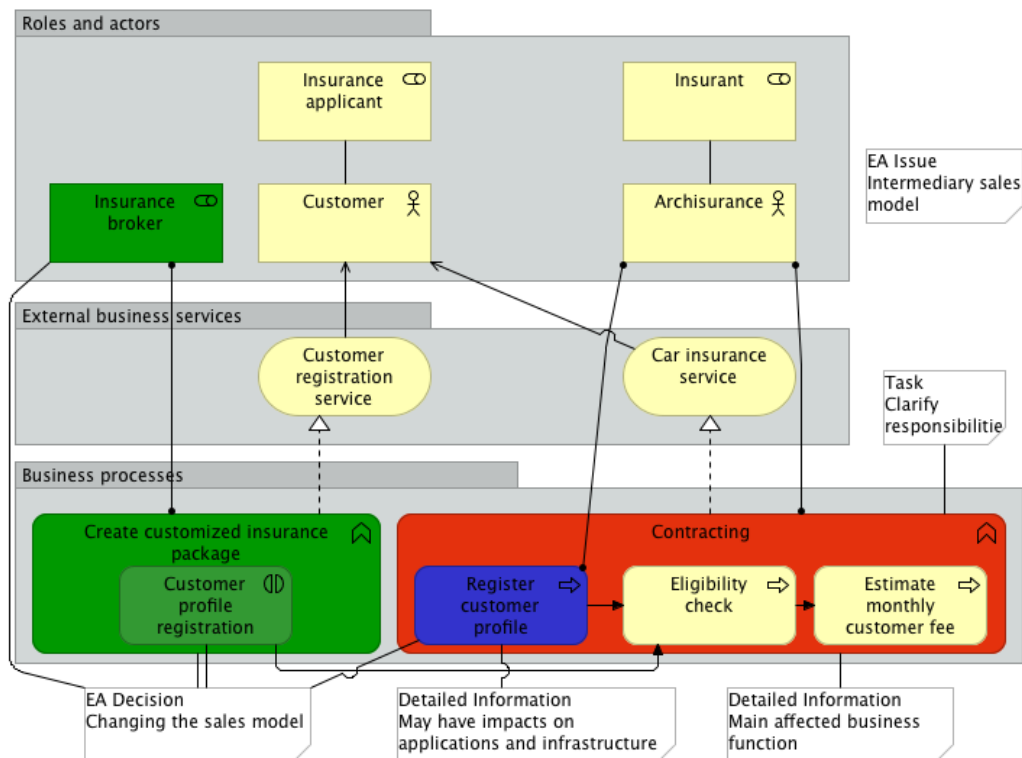


Figure 8. Adapted Business Process Viewpoint

Next the stakeholders have to analyze the impacts of the business process change on application services and applications by using the impact analysis function. In so doing, affected elements are assigned a new *Detailed Information* named “Impact Analysis of Register Customer profile” representing the analysis result and are highlighted with a brown fill color. The result is that the application service “customer administration service” has to be adapted to the new situation.

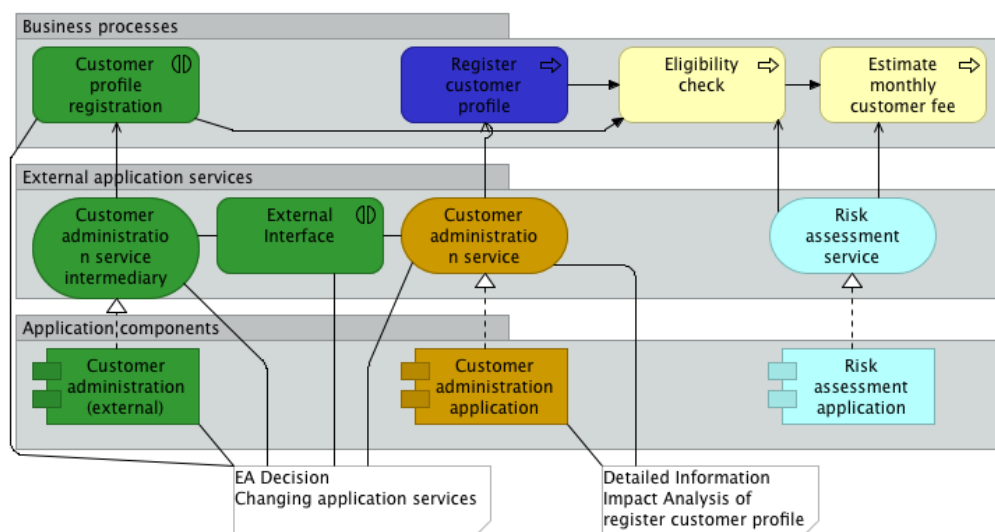


Figure 9. Adapted Application Usage Viewpoint

Mike recommends retaining the application service. To enable the intermediary he suggests using an external application service named “Customer administration service intermediary” that provides customer information from the intermediary. To combine the two application services, the internal one needs a new interface. Using this interface, the external service will have to send

the customer information to the other interface. Mike documents his idea by creating a correspondent *EA Decision* “Changing application services” according to the procedure described above. Thereby the *EA Decision* “Changing the sales model” is translated into the *EA Decision* “Changing application services”. Figure 9 illustrates the modified application landscape.

Jack - the infrastructure and security expert - has reservations because he expects security issues. He documents his argument by creating a *Detailed Information* named “Security Issues”. To consider impacts on the underlying infrastructure, they perform an impact analysis by choosing the application “Customer administration application”. Afterwards, Jack suggests some changes to the infrastructure. He recommends adding a new firewall that protects the application service “Customer administration service” within the enterprise’s LAN from undesirable external access. Therefore, he also creates an *EA Decision* named “Adding a Firewall” that is translated from the *EA Decision* “Changing application services”.

Finally, they have to further discuss whether the *EA Decisions* already discussed should be realized. They decide to also investigate other alternatives. A final decision will be taken at the next meeting. To get an overview of the decision-making process they use the Decision Viewpoint, which shows all relevant information during the process.

8 Related Work

ArchiMate [39] is a modeling language that also defines a notation for visualizing Enterprise Architectures. The underlying metamodel comprises several concepts on different layers and relationships between them. In its core ArchiMate focuses on modeling a static state of the EA, being the current or an intended future state. Two extensions to ArchiMate address more transformation-oriented aspects of EAM.

The motivational extension [39] allows the modeling of incentives and reasons for EA design. A *Stakeholder* is associated with a so-called *Motivational Element*. There are several characteristics of such an element. A *Motivational Element*, e.g., can be a *Driver*, *Goal*, *Principle*, *Requirement* or *Constraint*. These concepts are related to each other and, in our future research, are useful to capture the reasons for designing and refocussing of EAs.

The implementation and migration extension to ArchiMate [39] describes EA transformations in more detail. Thereby a *Gap* describes the differences between two states. The states are defined as *Plateau*. A *Plateau* is realized by *Deliverables*. The detailed work that has to be done is modeled with *Work Packages*. *Work Packages* are similar to a project that has *Deliverables* as its outcome. While both extensions deal with decisions, either from the aspect of their motivations or that of their impact on the architecture, an explicit decision concept focusing on the decision making process is currently missing. Therefore, we have extended this fundamental research by suitable decision and architectural concepts for digitization architectures and linked them with architectural artifacts.

In a similar manner, Buckl et al. discuss motivation and impact of EA transformations [70]. They combine the approach of Aier et al. described in [69] for modeling Work Packages and their impact on the EA with the i* modeling method [71] for describing motivations. While the modeling of transformations that is employed can be regarded as a refinement of implementation and migration extension, and i* modeling of motivation provides a refined perspective on, for example, soft goals; the approach does not provide an explicit concept for reflecting decisions.

Plataniotis et al. recognize the insufficiencies of the above approaches and describe in [67] an approach called EA Anamnesis focusing on ex-post modeling Enterprise Architecture decisions and the decision-making process. They have developed a fundamental and inspiring metamodel for this purpose. An *EA Issue* represents the starting point of a decision-making process. It describes the design problem that has to be addressed. The *EA Decision* is described as a representation of a design decision that is taken. *EA Decisions* result in an *EA Artifact*. The *EA*

Artifact is defined as a result produced by an *EA Decision*. Furthermore, it is described as a representation of the result. The intention is to use this concept to relate an *EA Decision* with a visual representation of ArchiMate. In addition an *EA Decision* is associated with a *Layer* of ArchiMate.

In addition, the approach provides four different relationships to relate *EA Decisions* with each other. *EA Decisions* can be translated into other decisions using the *Translation Relationship*. This relationship enables the deriving of *EA Decisions*. For instance, a stakeholder takes a decision on Business Layer. This decision has impacts on the underlying Application Layer. Therefore, the *EA Decision* on Business Layer has to be translated into an *EA Decision* on Application Layer and so on. Using *Decomposition Relationships* enables decomposing into more detailed decisions. Before a decision is taken, the person responsible usually has to choose between several alternatives. Such alternatives between *EA Decisions* can be modeled using the *Alternative Relationship*. Thus, *EA Decisions* may have negative impacts on the Enterprise Architecture. The *Substitution Relationship* enables modeling of how these negative impacts can be repaired. Furthermore the approach comprises concepts of modeling strategies for decision-making.

While the approach of Plataniotis et al. provides in [67] a significant contribution in the field, it is limited with respect to the challenges outlined in Section 1. Firstly, the authors assume that a single stakeholder takes the decisions and the process is straightforward. In practice many stakeholders are involved in decision-making. Secondly, in this approach, the intention is an ex-post documentation of decisions. While this is possible, we regard it as time-consuming and, in particular, not adequate in a collaborative setting.

Although Business Process Management [72] has concepts that have introduced a customer-oriented perspective, it still contains many concepts following the ideas developed already in [73]. These are the division of larger tasks into defined, smaller tasks and the assignment of individuals responsible to accomplish these tasks. Therefore, it is not surprising that plenty of approaches such as [74], [54] tried to develop support for cooperation beyond strictly structured business processes, as in almost all WFMSs and most of the BPMSs, but also in some groupware and case management systems. However, these approaches were less successful than expected for our research.

One inevitably meet a number of challenges when supporting EA management processes. The first challenge is the lack of a pre-defined workflow. Similar to adaptive case management [75], the control-flow of EA management processes cannot be predefined in most situations. Instead the control-flow is defined “on-the-fly” during execution of the EA management process.

The second challenge is organizational integration [75]. Many early approaches addressing the support of EA management processes limited the participation of stakeholders. E.g., although classical groupware abstained from pre-defining a strict control flow, specific access rights to documents had been assigned. Thus, the group of possible contributors had been limited. In this way a priori-decision had been made deciding who may contribute and who may not. Systematic decision making in digital enterprise architectures often requires a micro-managerial approach for decision making, which could not easily lead to fast decisions.

The third challenge detected in our research is the semantic integration [49] of architectural concepts and knowledge. Due to the involvement of a multitude of stakeholders, semantic frictions such as homonyms and synonyms create misunderstandings between the process participants. These semantic frictions may delay the EA management process or, even worse, may cause deficient architectures.

Social software is based on four basic principles, which have inspired our work: social production [76], weak ties [77], collective decisions [78], and value co-creation [79]. Social production [76] is the creation of artifacts without a top-down created plan but, instead, by combining the suggestions and decisions from independent contributors. By abstaining from Tayloristic top-down planning, new and innovative contributions, outside the original scope, can be identified and added. Due to these properties, social production matches the requirements of

EA management processes. The control flow of EA management processes can be defined in an ad-hoc manner. During execution of the EA process, artifacts, as architecture models, can be created in a cooperative way.

Collective decisions [78] in EA management processes provide a new way of making decisions. They provide statistically better results than experts, if the decision cannot be made using scientific means and the participants decide independently. Surowiecki describes in [80] the approach of the so-called wisdom of crowds. He argues that a decision made by several persons often leads to better results, because each person has specific knowledge. Value-co-production [79] is also supporting the definition and execution of EA management processes by integrating contributions from the business side. By abolishing the separation between artifact producer and consumer, a better adaptation to the individual requirements can be achieved. Furthermore value co-production enhances organizational integration.

Fundamental characteristics and requirements for Adaptive Case Management (ACM) have inspired our decision modeling approach and our decision processes and are elaborated in [64]:

- 1. The adaptation aspect of ACM consists of content, people, and reporting capabilities that are able to change the knowledge process at run-time by end-users. In addition to the adaptation aspect, a knowledge worker should be able to improve his case templates.*
- 2. The organization aspect groups policies, processes, and data. In ACM data is the dominant factor as opposed to the process-oriented view from BPM. Knowledge work requires the integration of data [64] into the execution process.*
- 3. The case handling aspect is about collaboration, decision support, and integration of resources, events, and communication. Complex problems are typically solved collaboratively by involving individual stakeholders in respect of different but necessary knowledge types and stakeholder concerns.*

9 Conclusion

In this paper we have identified the need for an integral understanding and support of collaborative decisions in the process of architectural adaptation and enterprise transformation. According to our research questions we have provided a main orientation for the digitization of products and services to fit into our era of digital transformation of both business and technologies. A main result of our investigation and improvement of digital enterprise architecture, and its related information systems, comes from current architectures for the Internet of Things. We have leveraged a new model of extended digital enterprise architecture, which is well suited for adaptive models and transformation mechanisms. We have extended the previous basic enterprise reference architecture, which was defined in a more static way, by new metamodel elements for supporting cooperative decisions using mechanisms from adaptive case management. With our original Architecture Management Cockpit we have developed new and extended models and collaboration mechanisms for decision support.

Related to our second research question we have presented our approach for collaborative processes in architectural engineering and transformation endeavors. We have additionally combined architectural engineering and transformation processes with elements from adaptive case management. We have extended typical architectural engineering processes with elements from social production, collective decision-making, value co-production, and weak ties. Adaptive case management, as in Section 5.3, offers a lightweight model for knowledge-intensive processes.

Finally, we have merged architectural viewpoints with user decision-making processes within cooperative distributed environments for enterprise architecture management. We have introduced suitable individual decision support models and embedded them into cooperative analysis and engineering environments. We are currently working on extended decision support mechanisms for an architectural cockpit for digital enterprise architectures and related

engineering processes. Additionally, we are currently considering elements from collaborative systems combined with semantic support, as in Gruber [81].

Future work will extend mechanisms for both adaptation and flexible integration of digital enterprise architectures and also will extend decisional processes by rationales and explanations. There is also a need to integrate more analytics based decision support [61], [82], and context-data driven architectural decision-making [83], [84].

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